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Research article

Effect of different resistance increments during warm-up on the snatch performance of male weightlifters

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ABSTRACT

This study investigated the effect of different resistance increments during warm-up on snatch performance of male weightlifters. Nine male college weightlifters were recruited. The 3 warm-up protocols were performed every 7 days with a randomized order: 1. Power snatch exercise with 10 % resistance increment (50 %, 60 %, 70 %, and 80 % of one-repetition maximum); 2. Power snatch exercise with 15 % resistance increment (50 %, 65 %, and 80 % of one-repetition maximum); 3. Self-selected resistance increment. Participants were tested based on 85 % maximum weight snatch after warm-up. Snatch performance was measured using peak vertical ground reaction force. Postural stability was measured using center-of-pressure displacement. Activation of seven shoulder, back, and leg muscles was measured using electromyography on the dominant side. In snatch performance, the 10 % increment protocol had a significantly higher peak vertical ground reaction force during the second-pull phase than the 15 % increment ($d = 0.92$, $p < 0.05$) and self-selected ($d = 1.32$, $p < 0.05$) protocols. In postural stability, no significant differences in center-of-pressure displacement among the three protocols were observed. For muscle activation, the 10 % increment protocol resulted in significantly higher activation of shoulder ($d = 1.2$–2.2, $p < 0.05$) during the second-pull phase than the other two protocols and higher activation of hip muscles ($d = 1.73$, $p < 0.05$) than self-selected protocol. To conclude, a warm-up protocol combining slow progression is preferable in improving power output during snatch in male weightlifters, probably through facilitating the activation of proximal limb muscles. It can enhance training quality while potentially reducing the risk of sports injuries.

1. Introduction

Weightlifters face injury risks during specialized strength training sessions. Warm-up exercises are typically conducted to enhance training quality, improve athletic performance, and mitigate injury risks [1]. However, improving athletic performance may be

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associated with the warm-up exercises inducing the phenomenon of post-activation potentiation (PAP). PAP is when the recruitment of motor units and efficiency of muscle contraction improve after high-intensity, ballistic, or plyometric conditioning activities [2,3]. The conditioning activities are usually biomechanically similar to the targeted task so that the same muscle groups are involved. The intensity and volume of the conditioning activities are often at 60%–90 % with one repetition maximum (RM) and 1 to 3 sets with 1–5 repetitions [3]. Studies have reported that PAP resulted in a moderate improvement in sprint (effect size: 0.51) and a small improvement in jump (effect size: 0.29) and throw (effect size: 0.26) [2].

The warm-up protocols to induce PAP could be of constant resistance or progressive resistance. Chatzopoulos and colleagues, for example, tested a constant resistance warm-up protocol using back half squat as a conditioning activity (90 % of 1RM, 1 set × 10 repetitions) on basketball, volleyball, handball, and soccer players. They observed a significant improvement in 10-m and 20-m sprints [4]. On the other hand, Tano and colleagues tested a progressive resistance warm-up protocol using back squat as the conditioning activity (4 sets [40 %, 60 %, 70 % and 85 % of 1RM respectively], 4–5 repetitions per set), and observed a significant improvement in sled push and sprint performance [5]. However, research on the impact of power snatch warm-up exercise on the snatch performance of weightlifters is still lacking.

Compared with the constant resistance protocol, a progressive resistance protocol might reduce the risk of injury and avoid the rapid development of fatigue that offsets the benefit of PAP. However, to our knowledge, few studies have investigated the design of a progressive resistance warm-up protocol. Specifically, questions related to how protocols with different increments affect the effects of PAP, as well as what might be the optimal rate of progression, have been largely unanswered.

Weightlifting competitions are primarily divided into the snatch and the clean and jerk [6]. Athletes often train explosiveness through these techniques, with the snatch yielding higher peak power output compared to the clean and jerk [7]. Thus, this study focused on snatch because this sport comprises both strength-demanding and power-demanding phases [8]. This study investigated the effect of different resistance increments during warm-up on the snatch performance of male weightlifters. Specifically, this study compared warm-up protocols, each having resistance increments of 10 % and 15 % in addition to a set of self-selected ones.

2. Methods

2.1. Participants

Based on the effect sizes observed from a previous study [9], a priori power analysis (G*Power 3.1.9.7) suggested a minimum number of 8 participants were required for this experiment. This study recruited nine male participants by convenient sampling from a college weightlifting team and had attended national championship. On average, they trained 5 times a week (3–4 h per session). To be eligible for inclusion, participants were required to have a minimum of 5 years of training experience. The exclusion criteria were having critical included any lower extremity and upper-extremity reconstructive surgery or unresolved musculoskeletal disorders that

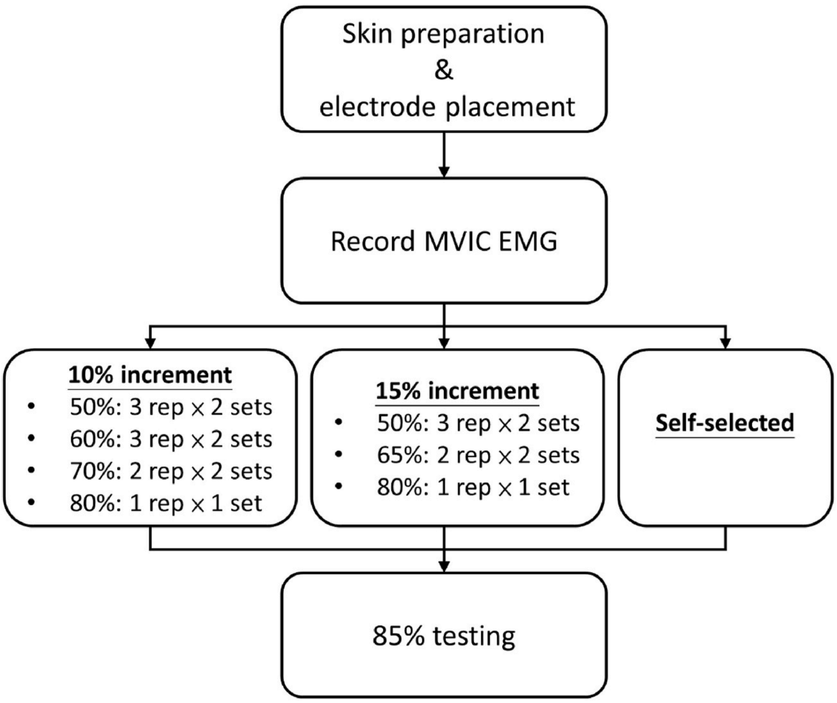

Fig. 1. Study procedure.

prohibited the participants from participating in sports, and having suspended training within the previous 6 months (defined as absence participation in any strength and conditioning training). All participants signed an inform consent form. This study was approved by the institutional review board of an area medical center. All the experimental procedures in this investigation were in accordance with the Declaration of Helsinki and approved by the Institutional Review Board Tsaotun Psychiatric Center (No.: IRB-107036).

2.2. Procedure

This study was conducted in the gym of a college weightlifting team. Participants were initially familiarized with the testing protocol 1 week before data collection, where the participants' power snatch 1RM were also determined. After the familiarization session, the 3 warm-up protocols were performed every 7 days with a randomized order. At each experimental testing visit, the participants started with a regular warm-up protocol which began with 5 min of running at 60–100 % of their perceived maximum speed. After the run, participants were given 5 min dynamic stretches for all joints, targeting calve, thigh, hip, and shoulder muscles. Subsequently, participants were instructed to perform one of the three warm-up protocols.

The conditioning activity was a repetitive power snatch, and warm-up protocols included a 10 % resistance increment (50 % [3 repetitions × 2 sets], 60 % [3 repetitions × 2 sets], 70 % [2 repetitions × 2 sets], and 80 % [1 repetition × 1 set] of one-repetition maximum); a 15 % resistance increment (50 % [3 repetitions × 2 sets], 65 % [2 repetitions × 2 sets], and 80 % [1 repetition × 1 set] of one-repetition maximum); and a self-selected resistance increment (Fig. 1). The participants performed power snatch exercise for each load with a rest interval of 3 min between loads.

The test procedure is illustrated in Fig. 1. First, participants cleaned their skin, placed the electromyography (EMG) electrodes on their bodies, and recorded activity under maximum voluntary isometric contraction (MVIC). Next, participants conducted the specified warm-up protocol. Finally, participants engaged in the snatch test with 85 % maximum weight (weight of heaviest successful snatch).

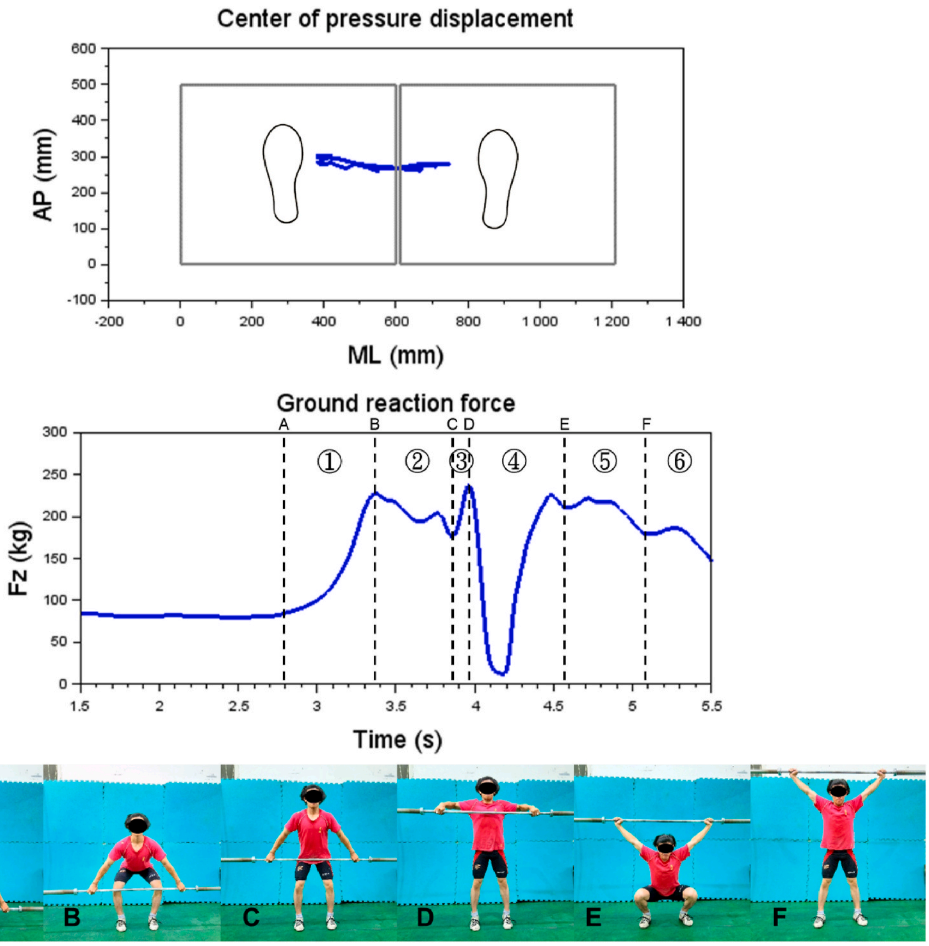

Fig. 2. COP displacement, vertical ground reaction force (Fz) and corresponding movement phases (① first-pull, ② transition, ③, second-pull, ④ turnover, ⑤ catch and ⑥ recovery) and positions (A: Start, B: Bar at knee level, C: Power position, D: Fully extended, E: Catch, and E: Fully recovered) during snatch. AP: Anteroposterior. ML: Mediolateral.

2.3. Measurements

Ground reaction forces of bilateral feet during the 85 % snatch test were measured using two piezoelectric force platforms (Kistler 9260AA; Kistler Instrument Corp., Winterthur, Switzerland). Activation of seven muscles of the shoulder (upper trapezius, middle deltoid), back (latissimus dorsi, erector spinae) and leg (gluteus maximus, vestus lateralis, and biceps femoris) during the 85 % snatch test were measured using a wireless EMG system (ZeroWire EMG system and acquisition software, Aurion, Italy). The electrodes were placed on the muscle belly of each muscle. The ground electrode was located on the patella of the dominant leg. Before testing, the surface of the skin was shaved, cleaned using alcohol, and rubbed with fine sandpaper to keep the impedance between the two electrodes low. The force platforms and wireless EMG system were synchronized and sampled at 1000 Hz by a control software program developed in LabVIEW (version 2014 sp1, National Instruments Corporation, Austin, TX, USA).

2.4. Data processing

Ground reaction forces of bilateral feet were low-pass filtered by a second-order Butterworth filter with a 10-Hz cutoff to remove high-frequency noise. Bilateral ground reaction forces were pooled into net ground reaction force and net center-of-pressure (COP). Fig. 2 illustrates the COP displacement, vertical ground reaction force, and corresponding movement phases/positions during a snatch. The EMG recordings of seven muscles were band-pass filtered using a second-order Butterworth filter with a 10–500 Hz pass band, rectified, and then linear enveloped by a second-order Butterworth filter with a 10-Hz cutoff.

Snatch performance was measured using peak vertical ground reaction force and duration in the second-pull phase. According to the previous study, it was found that the highest velocity and maximum force values are generated during the analysis of the snatch movement in the second pull phase [10]. However, weightlifters can improve their snatch performance by generating high speed [11], strength [12], and power [13] output during the execution of the snatch movement. The peak vertical ground reaction force in the second-pull phase was normalized by the heaviest successful snatch; this indicated the maximum capacity of power output. The duration of the second-pull phase indicated the rate of power output. Postural stability was measured using COP displacement in the sagittal and frontal planes in the second-pull phase. Muscle activation was measured using the root mean square EMG for the second-pull phase. The root mean square EMG was normalized by the MVIC; this indicated the mean activation level of muscles.

2.5. Statistical analysis

Baseline demographics were presented in terms of their mean and standard deviation. The effect of different resistance increments during warm-up on snatch performance, postural stability, and muscle activation was investigated using the Friedman test because of the limited sample size in this study. The Friedman test is a nonparametric test equivalent to a one-way ANOVA with repeated measures. The Wilcoxon signed-rank test was used for subsequent pairwise comparisons once the Friedman test reported a significant intragroup difference. Statistical tests were conducted using SPSS (version 21.0; SPSS Inc, Chicago, IL, USA). The effect size (Cohen's d) ($d = M1 - M2/\sigma$ pooled) was calculated to examine the magnitude of the effects between 2 different warm-up conditions. Statistical significance was at $p \leq 0.05$.

3. Results

The demographic characteristics of participants are listed in Table 1.

3.1. Snatch performance

Snatch performance was measured by the peak vertical ground reaction force in the second-pull phase and the duration thereof. Data on the peak vertical ground reaction force in the second-pull phase under different warm-up protocols are detailed in Fig. 3 (in kg) and Table 2 (in terms of the of heaviest successful snatch percentage). The Friedman test revealed a significant difference ($p < 0.01$) among the protocols, and pairwise comparisons indicated that the 10 % increment protocol had a higher peak vertical ground force in the second-pull phase compared with the 15 % increment ($d = 0.92$, $p = 0.020$) and self-selected ($d = 1.32$, $p = 0.004$) protocols. Data on the duration of the second-pull phase under different warm-up protocols are detailed in Fig. 3 and Table 2. The Friedman test revealed no significant difference among three protocols ($p = 0.359$).

Table 1
Demographic characteristics of participants.

	Participants (n = 9)
Age (year)	20.2 ± 2.2
Height (cm)	167.3 ± 6.8
Body weight (kg)	74.1 ± 12.4
Heaviest successful snatch (kg)	106.6 ± 15.0
Training age (year)	7.3 ± 1.33

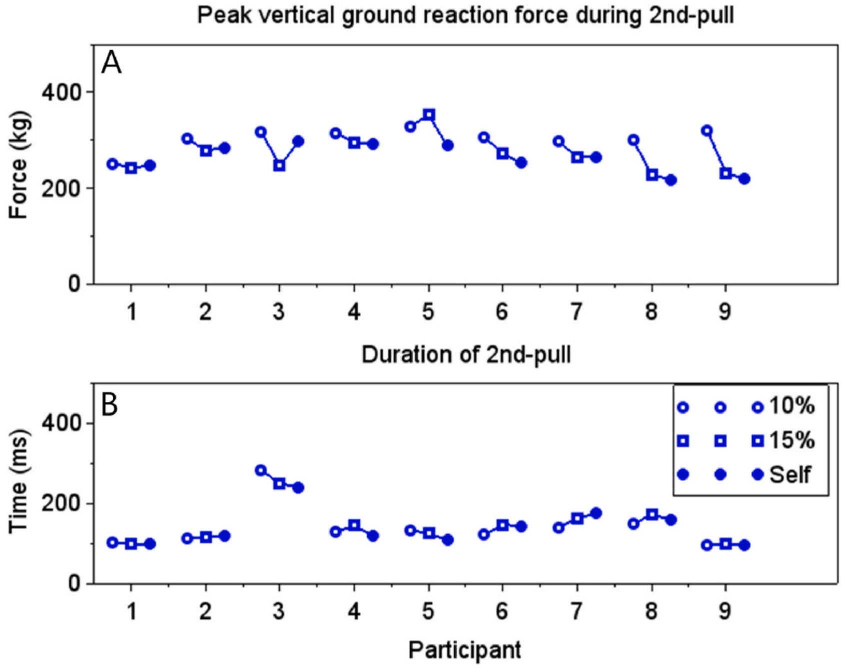

Fig. 3. Peak vertical ground reaction force (A) and duration (B) in the second-pull phase under different warm-up protocols in nine participants.

Table 2
Snatch performance and muscle activation under different warm-up conditions.

	10 % increment	15 % increment	Self-selected
Snatch performance			
Peak vertical ground reaction force (%)[1]	289.6 ± 36.7[a,b]	254.6 ± 39.6	248.4 ± 24.6
Duration (ms)	140.4 ± 56.2	145.7 ± 46.8	139.4 ± 46.5
Postural stability			
Sagittal COP displace (mm)	3.2 ± 1.6	5.0 ± 3.0	4.0 ± 1.7
Frontal COP displace (mm)	36.3 ± 14.1	46.4 ± 10.7	61.1 ± 33.1
Muscle activation			
Upper trapezius (%)[2]	107.0 ± 9.1[a]	93.6 ± 12.1	94.8 ± 17.0
Middle deltoid (%)[2]	111.9 ± 8.3[a,b]	100.1 ± 8.5[c]	87.6 ± 12.7
Latissimus dorsi (%)	99.9 ± 2.3	97.9 ± 2.7	95.7 ± 4.7
Erector spinae (%)[2]	103.2 ± 9.2	95.8 ± 13.9	99.1 ± 15.2
Gluteus maximus (%)[2]	112.5 ± 9.7[b]	100.7 ± 7.9	94.8 ± 10.7
Vestus lateralis (%)[2]	99.6 ± 12.5	95.7 ± 8.1	97.8 ± 13.7
Biceps femoris (%)[2]	99.6 ± 1.9	98.6 ± 3.1	96.4 ± 4.2

[1]Data are presented as heaviest successful snatch percentage.
[2]Data are presented as MVIC percentage.
[a] Significant difference between 10 % and 15 % increments.
[b] Significant difference between 10 % and self-selected increments.
[c] Significant difference between 15 % and self-selected increments.

3.2. *Postural stability*

Postural stability was measured using the sagittal and frontal COP displacement in the second-pull phase. Data on the COP displacement in the second-pull phase under different warm-up protocols are detailed in Fig. 4 and Table 2. The Friedman test demonstrated no significant difference in sagittal ($p = 0.398$) and frontal ($p = 0.278$) COP displacement among three protocols.

3.3. *Muscle activation*

Muscle activation was measured using the normalized root mean square EMG in the second-pull phase. Data on the root mean square EMG in the second-pull phase under different warm-up protocols are detailed in Fig. 5 and Table 2. Friedman test results yielded significant differences in the upper trapezius ($p = 0.016$), middle deltoid ($p = 0.001$) and gluteus maximus ($p = 0.048$). For the upper trapezius, pairwise comparisons indicated that the 10 % increment protocol had a higher activation level than the 15 % increment

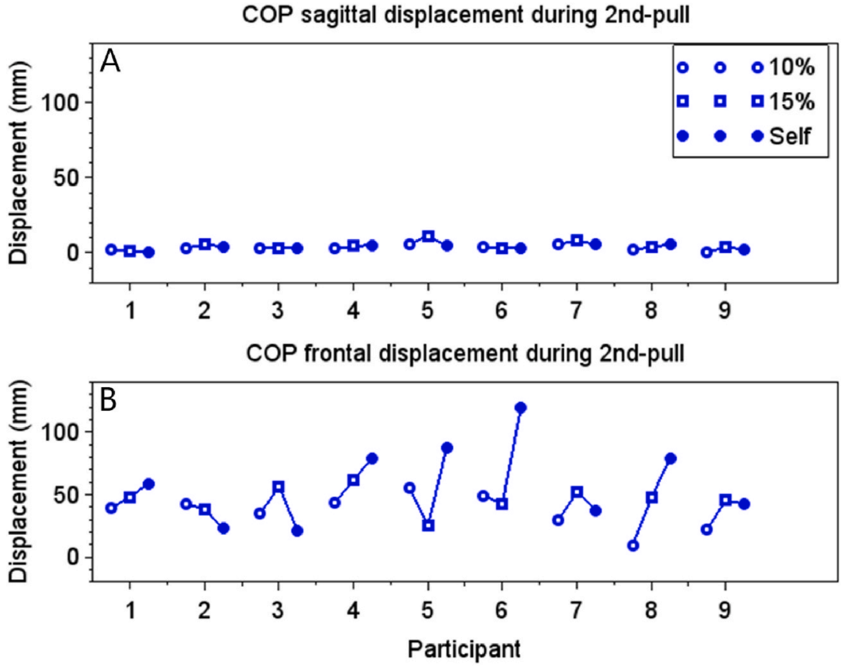

Fig. 4. COP displacement in sagittal (A) and frontal (B) axes in the second-pull phase under different warm-up protocols in nine participants.

protocol (d = 1.25, $p = 0.012$). For the middle deltoid, pairwise comparisons indicated that the 10 % increment protocol had a higher activation level than the 15 % increment (d = 1.4, $p = 0.004$) and self-selected (d = 2.27, $p = 0.008$) protocols. In addition, the 15 % increment protocol resulted in a higher activation level than the self-selected warm-up (d = 1.16, $p = 0.012$) protocol. For the gluteus maximus, pairwise comparisons indicated that the 10 % increment protocol had a higher activation level than the self-selected warm-

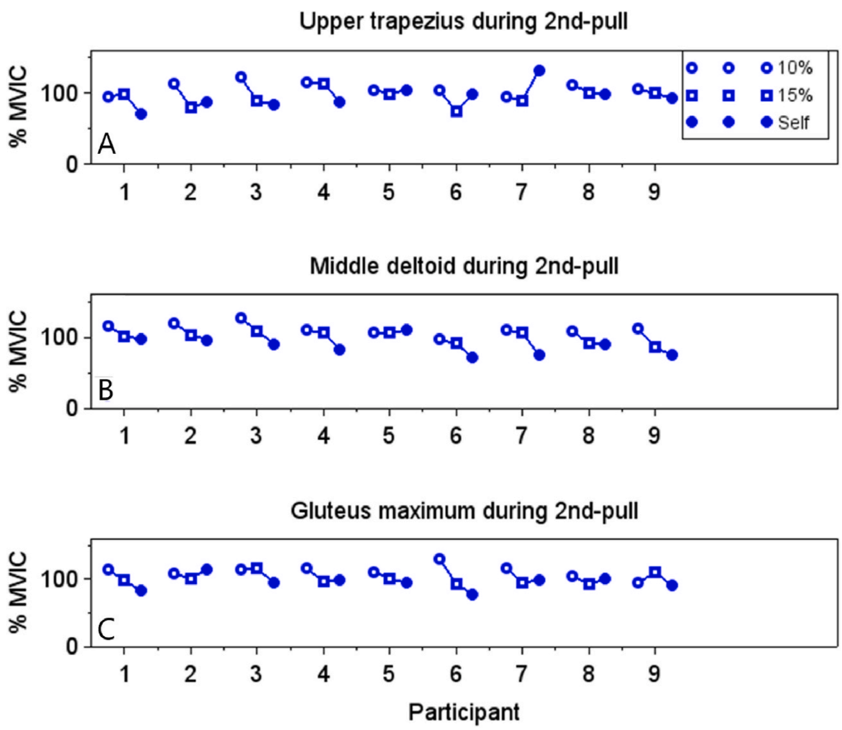

Fig. 5. Activation of the upper trapezius (A), middle deltoid (B) and gluteus maximus (C) in the second-pull phase under different warm-up protocols in nine participants.

up protocol (d = 1.73, $p = 0.020$).

4. Discussion

The purpose of this investigation was to examine the effect of different resistance increments during warm-up on the snatch performance of male weightlifters. Based on our results, the 10 % increment protocol had a significantly higher peak vertical ground reaction force during the second-pull phase than the 15 % increment and self-selected protocols. When examined the postural stability, no significant differences in center-of-pressure displacement among the three protocols were observed. However, the 10 % increment protocol resulted in significantly higher activation of shoulder during the second-pull phase than the other two protocols and higher gluteus maximus activation than self-selected protocol. In addition, the 15 % increment protocol resulted in a higher activation level than the self-selected warm-up protocol.

4.1. Differences between protocols

Most studies investigating the effect of PAP have employed a constant resistance warm-up protocol; reports of using a progressive resistance warm-up protocol are scarce. One review article summarized the results of relevant PAP studies in male and female athletes and concluded that a PAP warm-up protocol should have three characteristics. First, the conditioning activity should be biomechanically similar to the target task. Second, the resistance should be approximately 60 %–90 % of 1RM, and third, the volume should to be 1–5 repetitions × 1–3 sets [3].

This study investigated the effect of progressive resistance warm-up, thus addressing a gap in the literature. Specifically, this study investigated how warm-up protocols with different resistance increments affect snatch performance as well as what the optimal progression could be. In the self-selected protocol, as expected, participants preferred to conduct warm-ups at a low resistance (<80 % 1RM) level and with a small number of sets (mostly <4). Therefore, our interest was in comparing the 10 % and 15 % increment protocols. The first features a slow progression with a large number of sets (seven sets) and the second features fast progression with a small number of sets (five sets).

4.2. Snatch performance

The 10 % increment protocol was observed to have a higher peak vertical ground force in the second-pull phase than the 15 % increment protocol, indicating that the 10 % increment protocol could improve participants' muscle power. PAP has been shown to improve both muscle strength and power [2,3]. In the phases of snatch, the first-pull is a strength-related movement featuring a slower bar lift velocity (1.13–1.26 m/s), and the second-pull is a power-related movement featuring a faster bar lift velocity (1.68–1.98 m/s) [8]. The current results suggest that the difference in resistance increments primarily affects muscle power; this finding may help athletes lift heavier weights.

Several factors may contribute to the increased power output in the second-pull phase, such as improved postural stability, which allows more efficient force transfer between segments as well as increased muscle activation (especially large motor units with type II fibers). In this study, postural stability was measured using COP displacement and muscle activation was measured using EMG. The 10 % and 15 % increment protocols resulted in significant differences in muscle activation but not in COP displacement. Therefore, it was muscle activation, especially of proximal limb muscles, rather than postural stability, that led to the increased power output in the second-pull phase. The increased ground reaction force may be the result of a more effective energy store and return in parallel and series viscoelastic components of lower limbs or a more effective motor unit force production [14]. Indeed, it has been reported that increased leg stiffness was strongly correlated with increased maximal ground reaction force and flight time [15].

4.3. Postural stability

Snatch performance is affected by postural stability during bar lifting. Specifically, minimizing bar displacement in the anteroposterior direction during lifting increases the success rate of snatch [8]. Although this study did not measure bar displacement, it was still possible to monitor postural stability during snatch by observing COP displacement. Once a participant lifted the bar off the ground, the participant and bar became a linked system. Biomechanically, the forward acceleration of this bar–participant system is generated once the COP falls behind the system's joint center of mass, and vice versa [16]. Therefore, the anteroposterior and mediolateral displacement of COP could indicate the stability, during snatch, of this bar–participant system in the sagittal and frontal planes, respectively.

In this study, different resistance increments had no effect on COP displacement in the second-pull phase. This result is consistent with the current consensus [2]. It indicates that different warm-up protocols might vary the effect of PAP but not motor control and skill. García-Pinillos and colleagues investigated the effect of PAP on leg joint kinematics during countermovement jump in endurance runners [17]. Despite some participants having improved countermovement jump performance after 20-m shuttle run conditioning, no significant differences in hip, knee, and ankle joint angles during the phases of countermovement jumps were observed. Therefore, based on the results of COP displacement, the effect of different resistance increments on snatch performance could not be attributed to postural stability. Furthermore, although this study did not measure joint kinematics, the effect of different resistance increments on snatch performance was likely to be unrelated to varied joint kinematics.

4.4. Muscle activation

It is believed that both muscular and neural mechanisms contribute to the effect of PAP on muscle strength and power. The muscular mechanism of PAP results from an increased phosphorylation of the myosin light chain, especially among the type II muscle fibers [18,19]. The neural mechanism of PAP results from an increased recruitment of large motor units [20,21]. In this study, the 10 % increment protocol resulted in higher activation of the upper trapezius, middle deltoid, and gluteus maximus than the 15 % increment and self-selected protocols. These results suggest that the effect of different resistance increments could at least be attributed to the increased recruitment of motor units, especially of the proximal muscles over the upper and lower extremities, which also increases ground reaction force. The findings are consistent with previous study, showing that the increase in EMG activity is associated with greater force output [22]. For example, Fukutani et al. (2014) reported that an increase in both twitch torque and jump height in both heavy condition (45 % RM x 5 repetitions, 60 % RM x 5 reps, 75 % RM x 3 reps, and 90 % RM x 3 reps) and moderate condition (45 % RM x 5 reps, 60 % RM x 5 reps, and 75 % RM x 3 reps) [9].

Furthermore, studies have shown that muscles with shorter twitch contraction time, primarily the type II fibers, demonstrated greater PAP [23,24]. In addition, autopsy studies have revealed that proximal limb muscles have more type II muscles than distal ones [25,26]. These findings may explain why the effect of different resistance increments on muscle activation levels was prominent on the proximal limb muscles.

In a fitness–fatigue model, muscle strength and power improved once the development of muscle potentiation after high-intensity conditioning activities outweighed the development of fatigue [27]. Therefore, an ideal conditioning activity should facilitate the development of potentiation while avoiding the rapid development of fatigue. In this study, the 10 % increment protocol included a total of seven sets of repetitions. This is high relative to the generally suggested number of sets [2,3,28]. Notably, our results indicated that the 10 % increment protocol (featuring slow progression and a large number of sets) was superior to the 15 % increment protocol (featuring fast progression and a small number of sets) in facilitating muscle activation. It is speculated that the slow progression and high repetition of the 10 % increment protocol was better for recruiting motor units with different sizes and avoiding the rapid development of fatigue. However, further studies are required to confirm this.

4.5. Limitation

This study has several limitations. First, the study had only nine participants. Therefore, nonparametric statistical approaches were used. In addition, only adult, male weightlifters were recruited in this study; thus, it remains uncertain if the results apply to adolescent or female weightlifters, light and heavyweight weightlifters. One study reported that the effect of PAP induced by constant resistance conditioning (maximal isometric squats) was less obvious in adolescent and female subgroups [29]. It is possible that a progressive resistance design, similar to that of this study, might confer greater benefits on these two populations. Finally, this study did not directly use heaviest successful snatch as a performance indicator due to concerns, by the institutional review board, pertaining to the safety of the participants and damage to the instruments. Thus, this study measured peak ground reaction force in the second-pull phase to indicate snatch performance.

5. Conclusion

A warm-up protocol combining slow progression and a large number of sets is preferable in improving power output during snatch performance in male weightlifters. This improvement is probably achieved by facilitating the activation of proximal limb muscles. It could be used as a warm-up strategy before training or competitions, potentially reducing the risk of injuries and enhancing snatch performance.

Two clinical implications can be drawn from this study. First, when designing a progressive resistance warm-up protocol for improving the snatch performance of male weightlifters, slow progression and a large number of sets are superior to fast progression and a small number of sets. Second, the effect of the difference in warm-up protocols primarily affected movements requiring muscle power, probably by facilitating the activation of proximal limb muscles. Future research can further compare the progressive resistance and constant resistance protocols, especially with regard to differences in movement kinematics and proximal muscle activation in the second phase.

Ethical approval

The study was approved by the Institutional Review Board Tsaotun Psychiatric Center (No.: IRB-107036).

Informed consent statement

Consent was obtained from all study participants.

Funding statement

This research received no external funding.

Data availability statement

All data is available in the manuscript.

CRediT authorship contribution statement

Wen-Chieh Yang: Writing – review & editing, Supervision, Software, Methodology, Formal analysis, Data curation. **Shin-Yuan Wang:** Methodology, Investigation. **Chih-Hui Chiu:** Writing – review & editing, Project administration. **Xin Ye:** Writing – review & editing. **Ming-Chia Weng:** Supervision, Methodology, Investigation, Conceptualization. **Jhih-Ciang Jhang:** Project administration, Investigation. **Che-Hsiu Chen:** Writing – review & editing, Writing – original draft, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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